Cooling Water Treatment Principles

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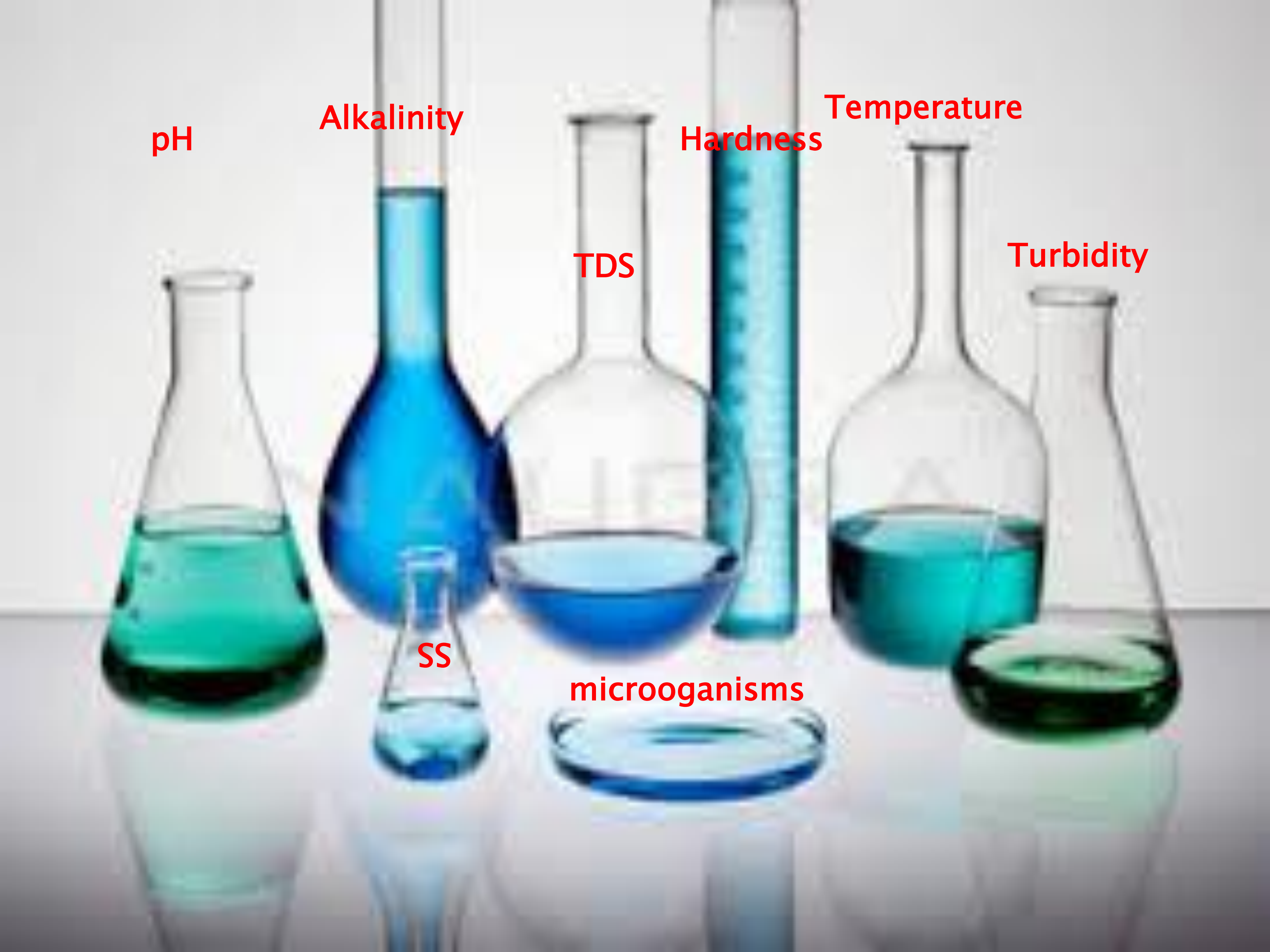
H_2O
TDS
Gases
SS
Microorganisms


pH
Alkalinity
TDS
Hardness
Temperature
Turbidity
SS
microoganisms

Cooling Systems

Why ,, imagination

$$A + B \xrightarrow{\Delta} C$$

Types of Cooling Systems

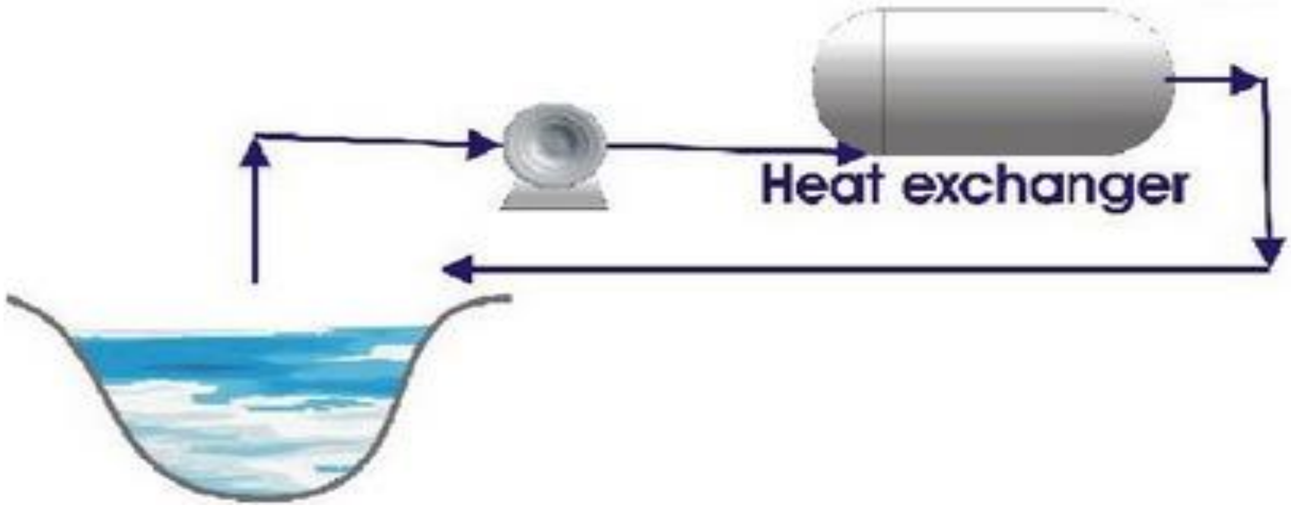
1. Once Through

2. Closed Recirculating

3. Open Recirculating

Types of Cooling Systems

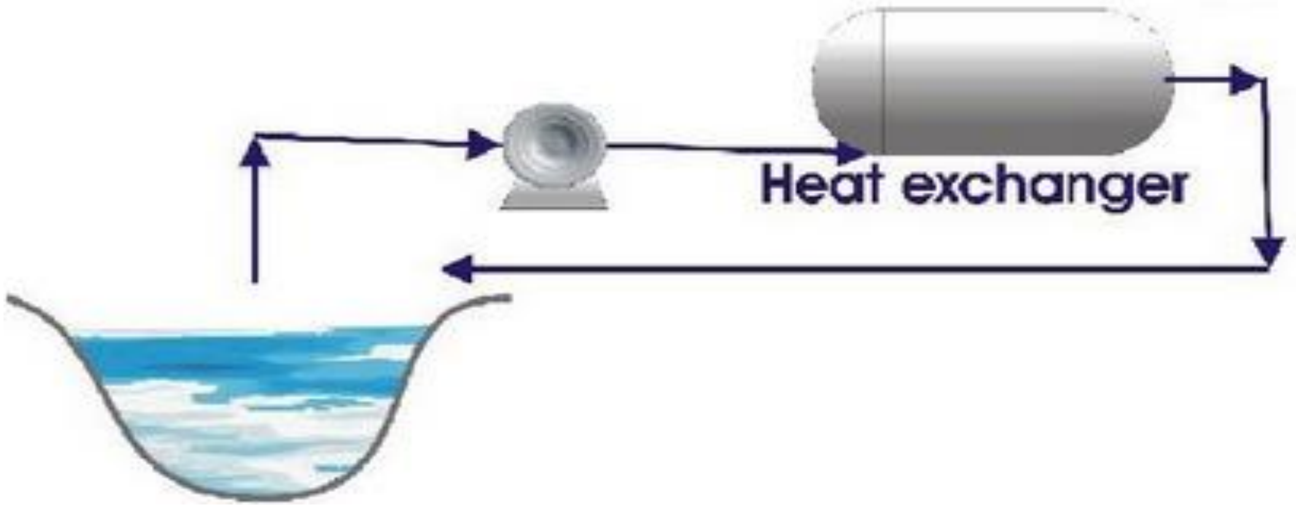
1. Once Through



- Simplest type
- Water passes through heat exchangers only one time
- Discharged back to original source
- Mineral content of water remains unchanged

Types of Cooling Systems

1. Once Through

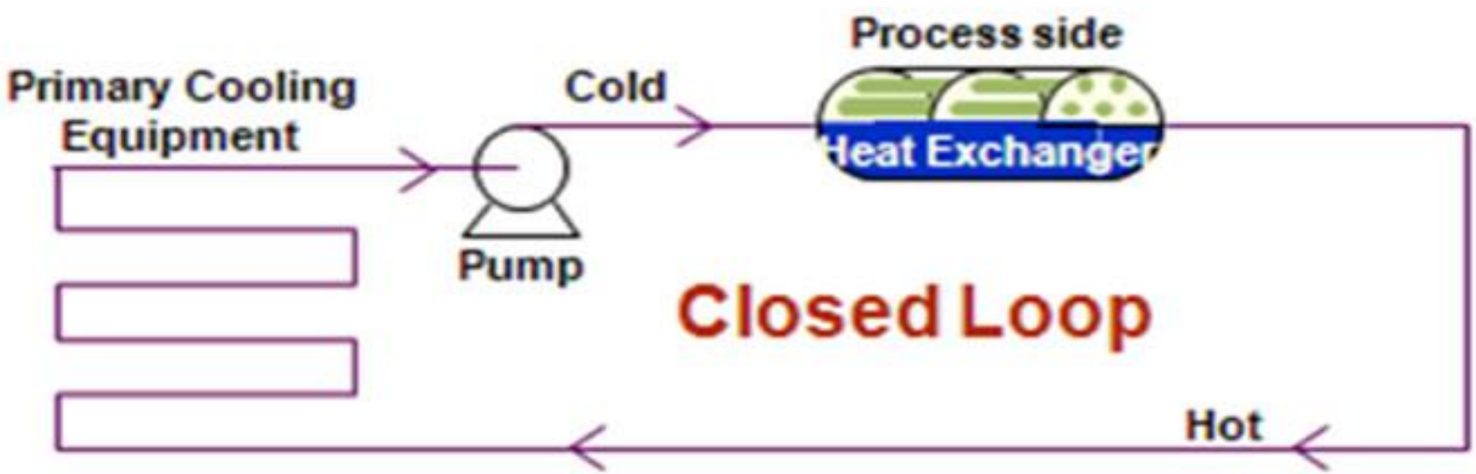


Advantages

Disadvantages

Types of Cooling Systems

2. Closed Recirculating



EXAMPLES

Mold & machine cooling
Jacket reactors
Diesel Engine Jackets
Automobile Radiators
Chilled Water Systems

CHARACTERISTICS

Cooling by Heat Transfer <u>and</u> Primary system
Average Temperature Change 5-10°C
Amount of Water Used: Negligible

Types of Cooling Systems

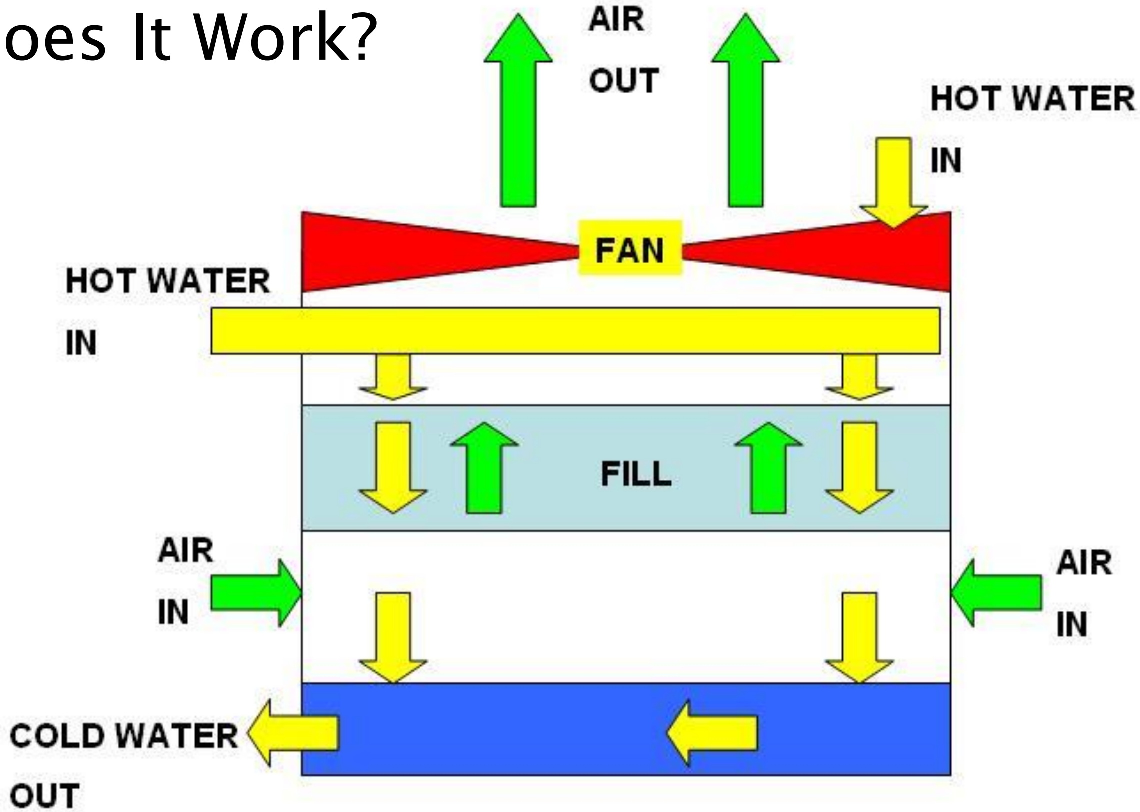
2. Closed Recirculating

- Advantages
  - Fixed volume of cooling water
  - No water is evaporated.
  - No water loss (except leaks)
  - No Scale in most closed circuits
- Disadventages
  - Corrosion
  - Microbial growth

Types of Cooling Systems

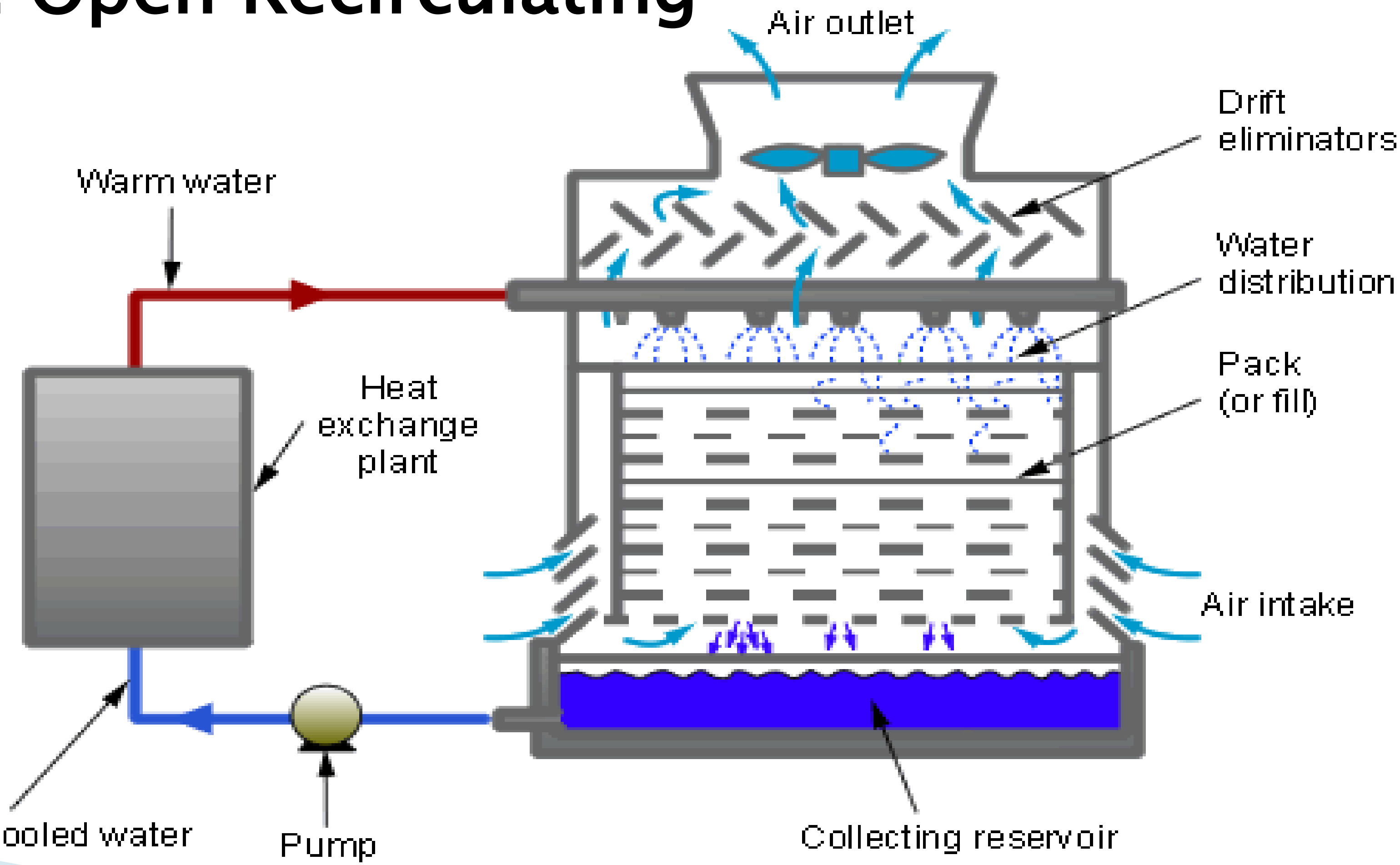
3. Open Recirculating

How Does It Work?



Types of Cooling Systems

3. Open Recirculating

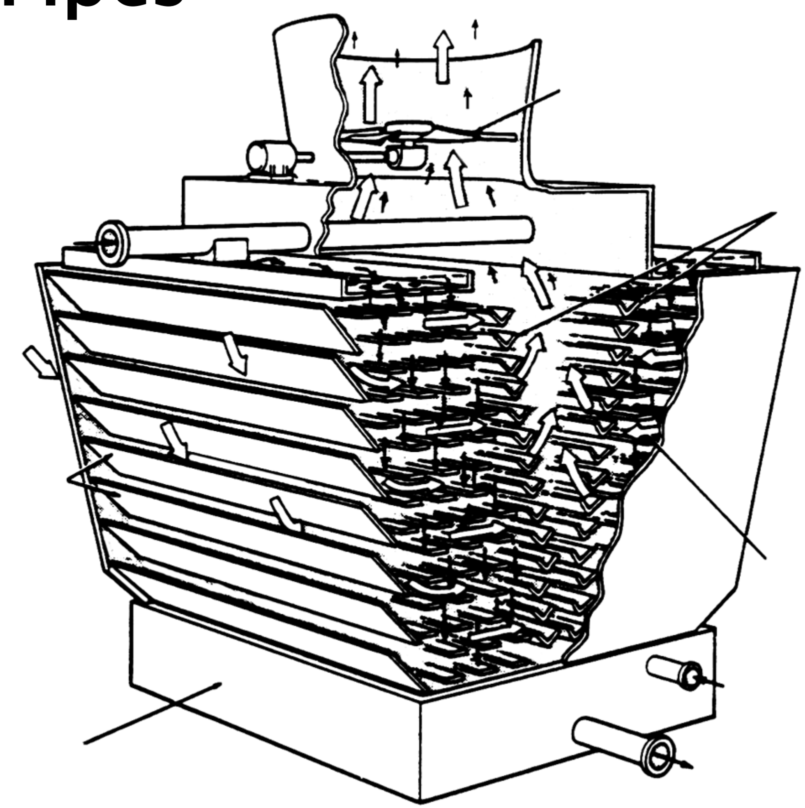


Components of Cooling Systems

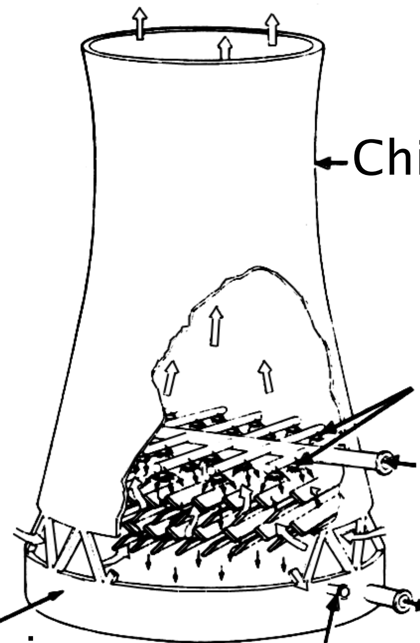
Cooling Tower

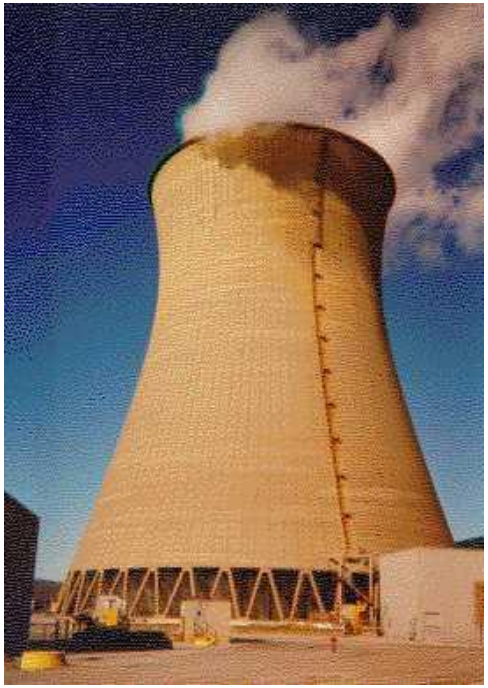
- Frame and Casing
- Filling material
- Cold water basin
- Drift eleminator
- Louvers
- Nozzles
- Fans and motors

Recirculating pumps
Heat exchangers
Pipes



Types of Cooling Towers





Natural Draft

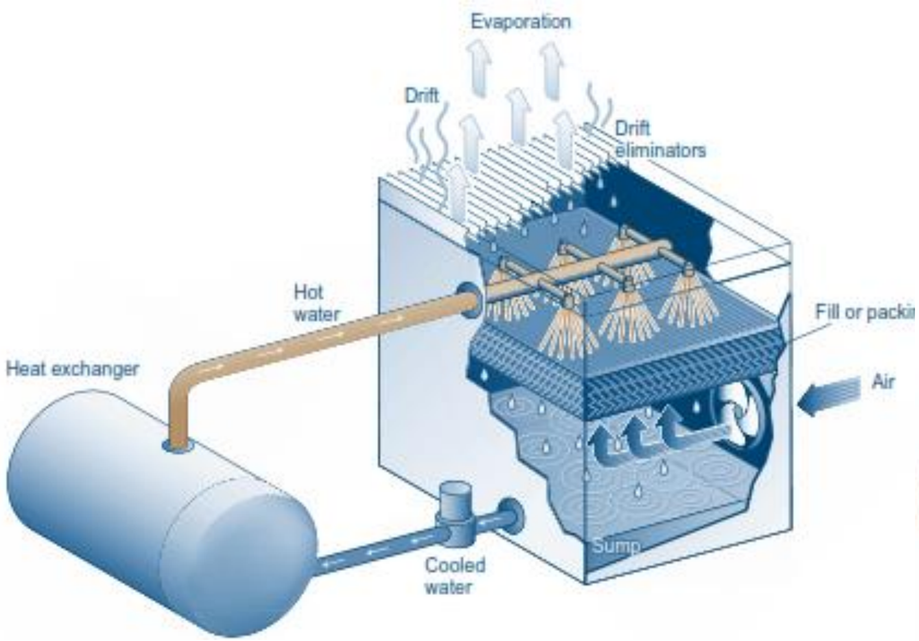
Types of Cooling Towers

Forced Draft Towers

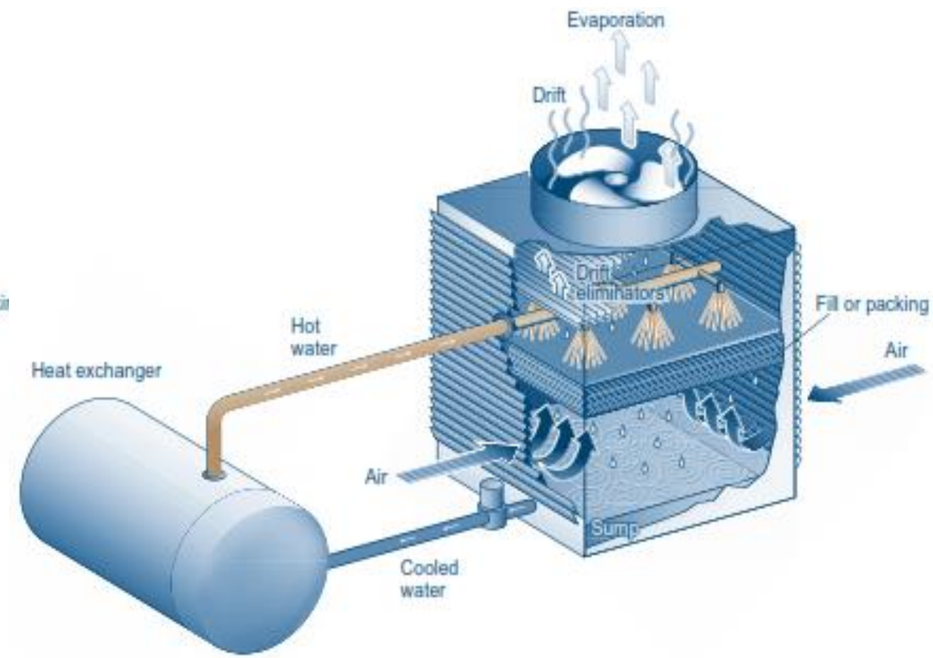
Induced Draft Towers

Mechanical Draft

Types of Cooling Towers



Forced Draft Towers

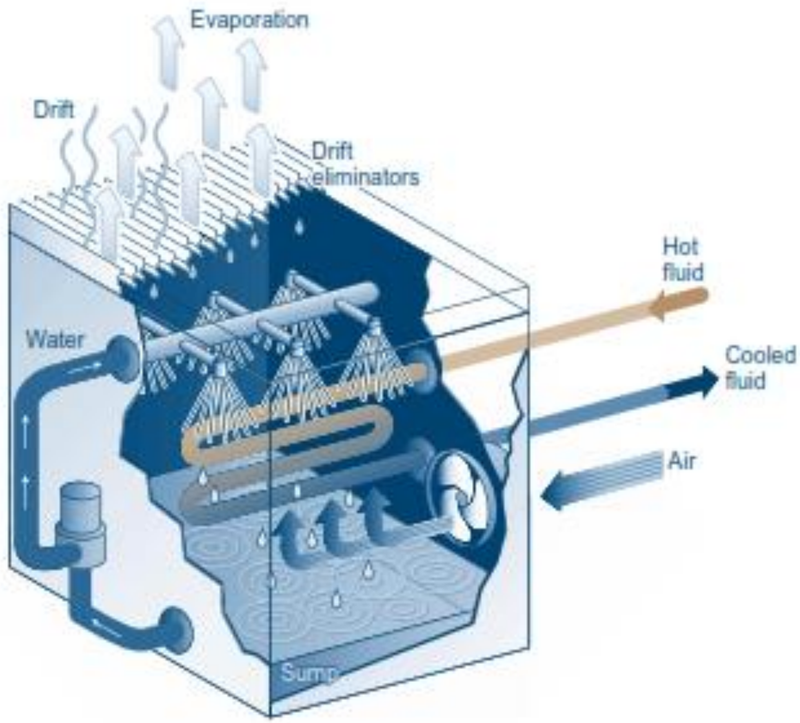


Induced Draft Towers

Mechanical Draft

Types of Cooling Towers

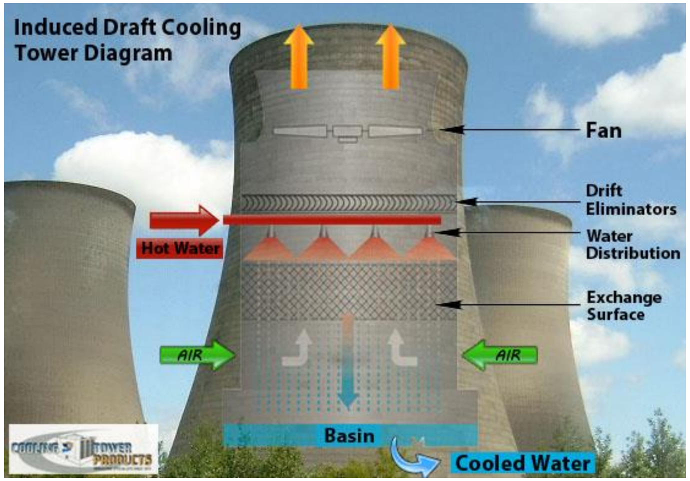
A device that cools air through the evaporation of water

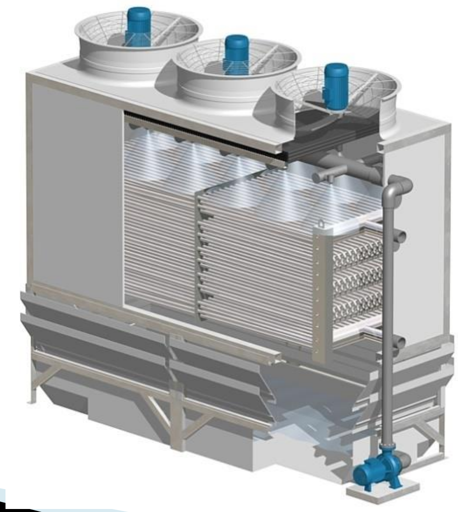


Evaporative cooler

Types of Cooling Systems

Types of Cooling Systems





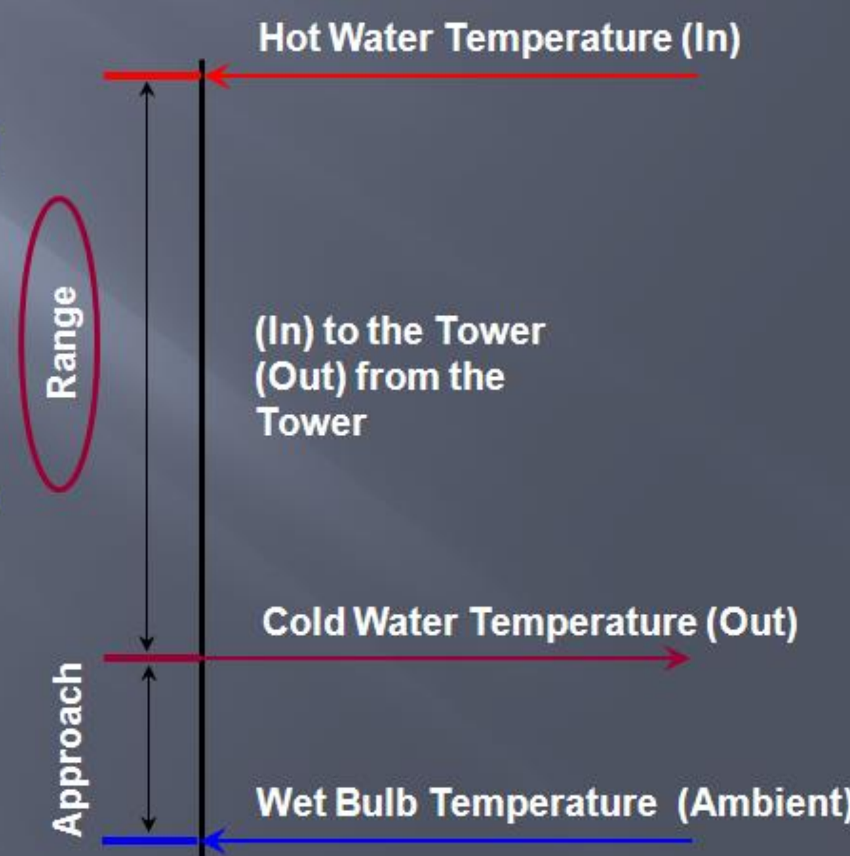
Terms and Definitions

1. Range

Difference between cooling water inlet and outlet temperature:

Range (°C) = CW inlet temp – CW outlet temp

High range = good performance



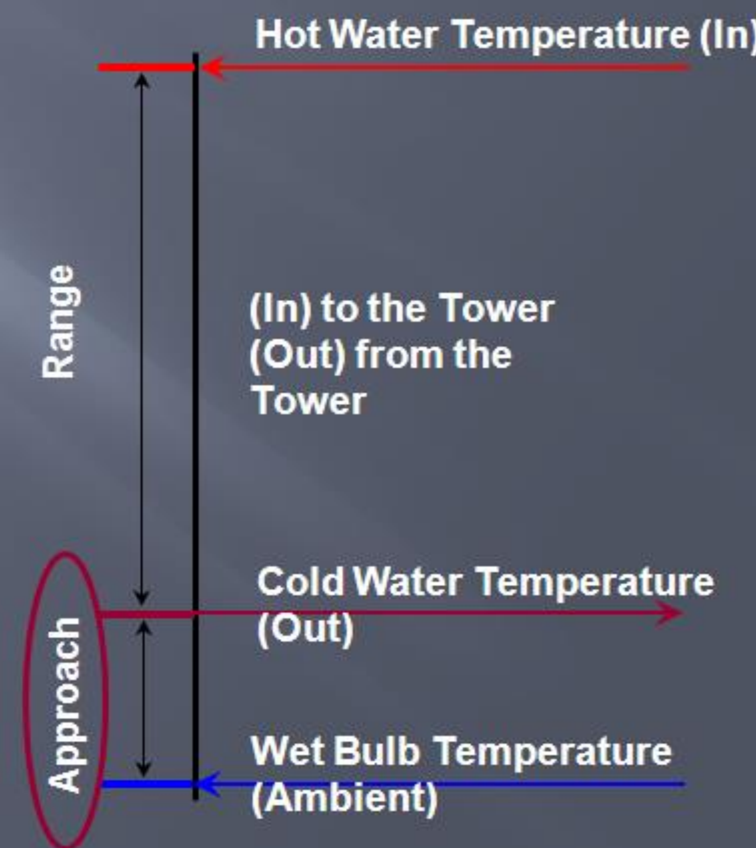
Terms and Definitions

2. Approach

Difference between cooling tower outlet cold water temperature and ambient wet bulb temperature:

Approach (°C) =
CW outlet temp – Wet bulb temp

Low approach = good performance



Terms and Definitions

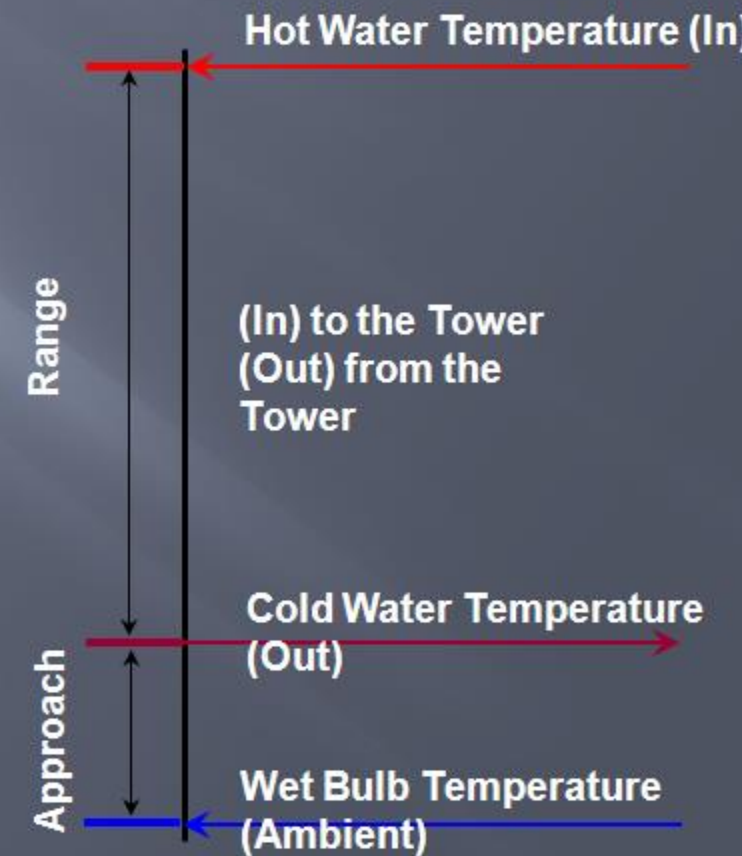
3. Effectiveness

Effectiveness in %

= Range / (Range + Approach)

= 100 x (CW temp – CW out temp) / (CW in temp – Wet bulb temp)

High effectiveness = good performance



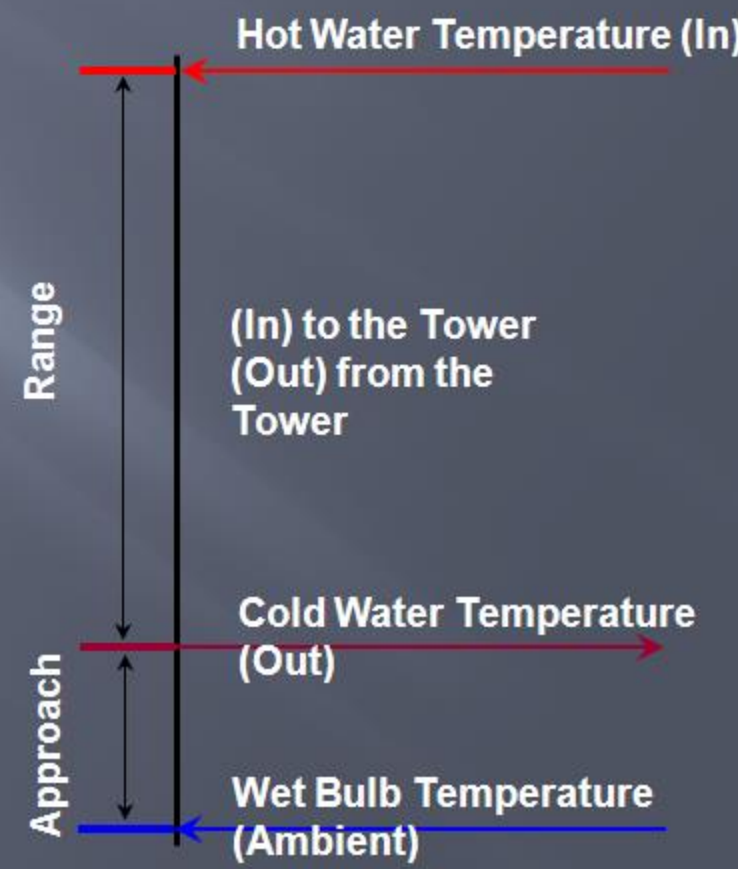
Terms and Definitions

4. Cooling Capacity

Heat rejected in kCal/hr or tons of refrigeration (TR)

= mass flow rate of water X specific heat X temperature difference

High cooling capacity = good performance



Terms and Definitions

T1 = 20ºC
T2 = 30ºC
Wet Pulp = 17ºC
Efficiency = ??

T1 = 22ºC
T2 = 38ºC
Wet Pulp = 20ºC
Efficiency = ??

Which is better?

Cooling Parameters

- <u>Recirculation Rate (RR)</u>
- <u>Evaporation (Evap)</u>
- <u>Make up (Mup)</u>
- <u>Blowdown (BD)</u>
- Cycle of Concentration (C.C), (N.C)
- Each 10°F that the RR needs to be cooled, one percent of the cooling water is evaporated.

Make up & blow down

Make up =evaporation +blow down

- MU =Evap + BD
- C.C = MU/BD >>> MU=BD * C.C
- BD*C.C =Evap+ BD

$$BD = \frac{evp}{(c.c-1)}$$

Cooling Parameters

- **<u>Example</u>**
  - T1= 85F T2= 75F
  - TDS inlet= 200 T2= 500ppm
  - RR= 4400 gpm

  - Calculated (Evap, BD and Mup)

Circulating Water Quality Guidelines

Property of Water	Recommended Level
pH	6.5 to 9.0
Hardness as $CaCO_3$ Alkalinity as $CaCO_3$	30 to 750 ppm 500 ppm maximum
Total Dissolved Solids	1500 ppm maximum
Conductivity	2400 micromhos
Chlorides	250 ppm maximum as Cl 410 ppm maximum as NaCl
Sulfates	250 ppm maximum
Silica	150 ppm maximum

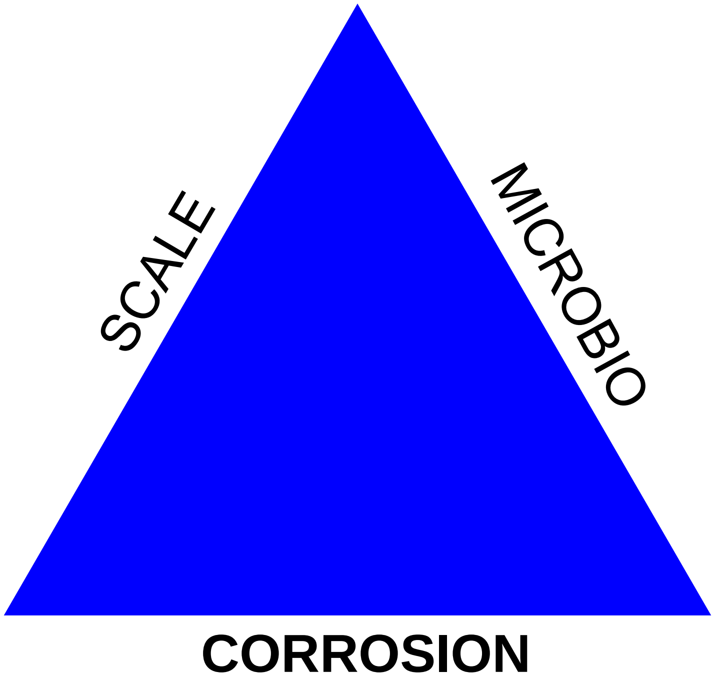
Water Chemistry

pH
Alkalinity
Hardness
Silica
Nitrate & nitrite
Phosphate
Ammonia
Chloride
Fluoride

Iron
Zinc
Cu
Ni
Suspended Solids
Organics
Bacteria

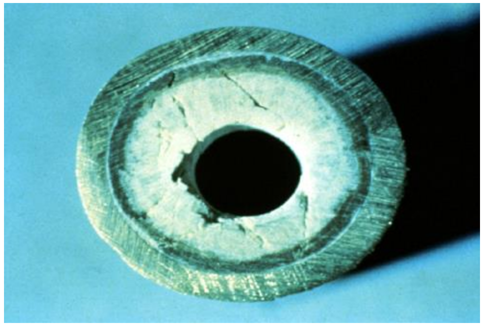
Cooling Systems Problems

- Scale
- Corrosion
- Biological growth
- Fouling



Scale

- Scale is the formation of **mineral deposits**.
- Solids precipitate when they reach the **limit of their solubility**.



$CaCO_3$

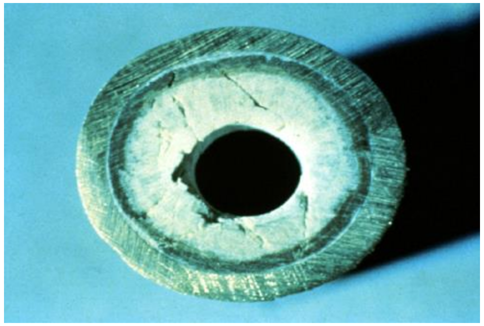
Common Scales

- Calcium Carbonate
- Magnesium Silicate
- Calcium Phosphate
- Calcium Sulfate
- Iron Oxide
- Iron Phosphate
- Zinc Phosphate
- Others...

$CaPO_4$

Factors affecting scale formation

- Mineral Concentration
- Water Temperature
- pH
- Flow rate
- Retention time
- Heat flux and skim temperature of heat exchanger.



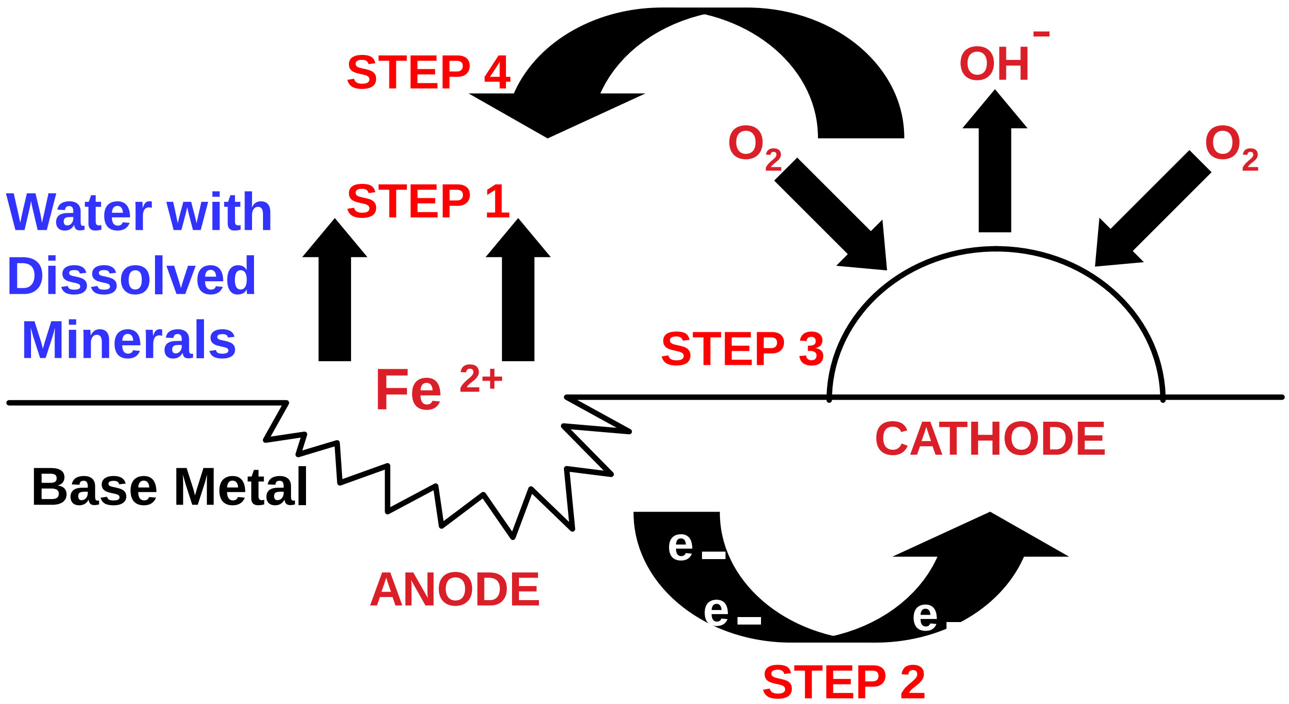
$CaCO_3$

$CaPO_4$

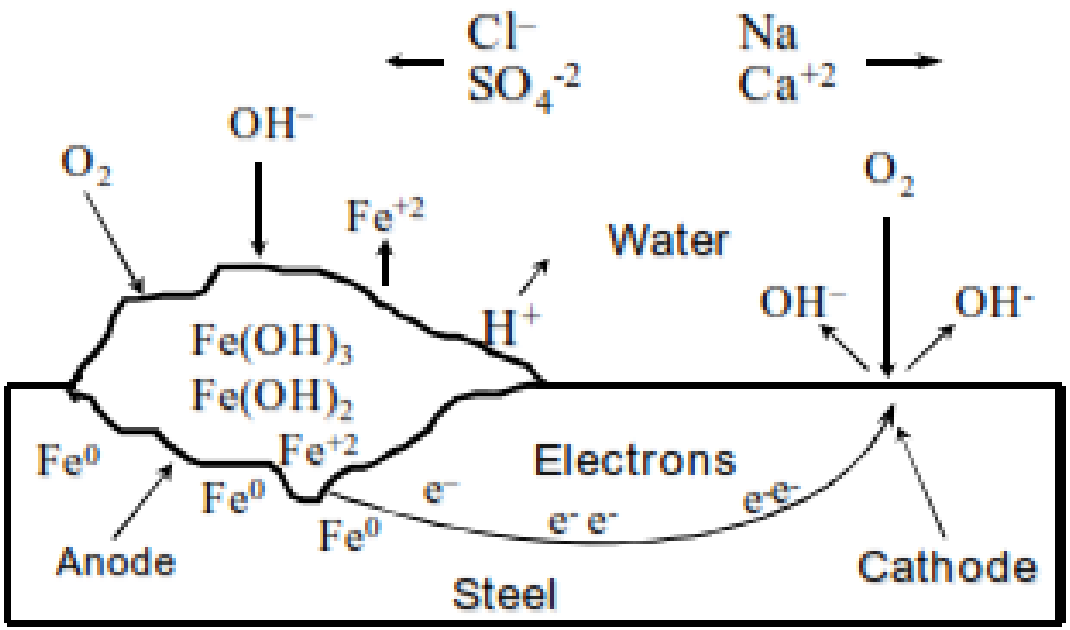
Prevention

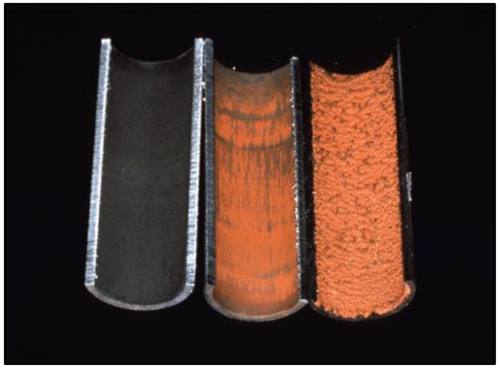
Corrosion

- The mechanism by which metals are reverted back to their natural "oxidized" state
- Corrosion required metal, oxygen and water.



Corrosion


Cl⁻
SO_4^{-2}
Na
Ca^{+2}
OH^-
O_2
Fe^{+2}
Water
O_2
OH^-
OH^-
H^+
$Fe(OH)_3$
$Fe(OH)_2$
Fe^{+2}
Fe^0
Electrons
e^-
Fe^0
e^- e^-
e^-e^-
Fe^0
Anode
Steel
Cathode



Corrosion

- For corroding metals, the anodic reaction is of the form

$$M \rightarrow M^{n+}_{interface} + ne^{-}$$ Charge Transfer

$$M^{n+}_{interface} \rightarrow M^{n+}_{bulk}$$ Mass Transfer

- Cathodic reaction is of the form

In acidic medium

$$H^{+}_{bulk} \rightarrow H^{+}_{interface}$$

$$2H^{+} + 2e^{-} \rightarrow H_2$$

$$½\, O_2 + 2H^{+} + 2e^{-} \rightarrow H_2O$$

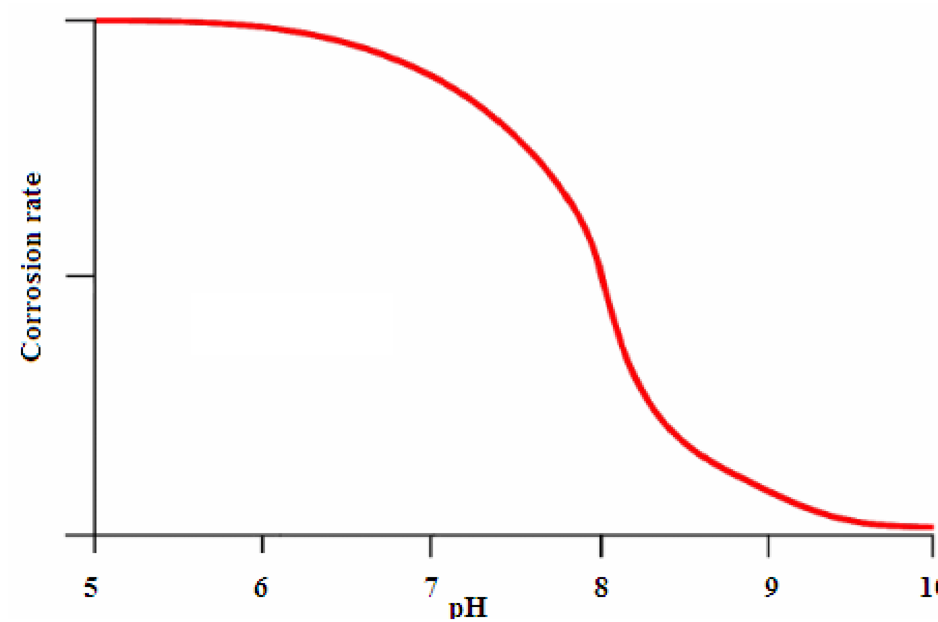
In Alkaline medium

$$O_2 \text{ bulk} \longrightarrow O_{2\ \text{interface}}$$

$$½\, O_2 + H_2O + 2\, e^{-} \longrightarrow 2\, OH^{-}$$

Factors affecting Corrosion formation

- pH
- TDS
- DISSOLVED GASSES
- Microorganisms
- Temperature
- Metallurgy



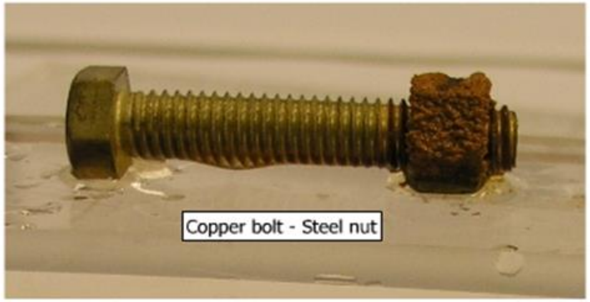
Corrosion Control

- Use corrosion resistant alloys
- Adjust (increase) system pH: Scale
- Apply protective coatings
- Use sacrificial anodes: Zn/Mg
- Apply chemical corrosion inhibitors

Forms of Corrosion

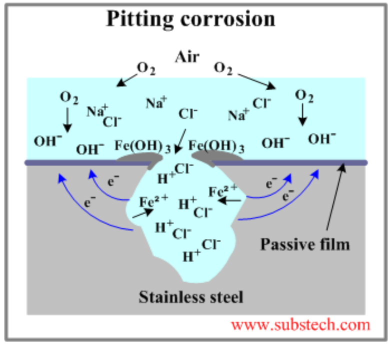
- **Uniform Corrosion**

- **Galvanic Corrosion**

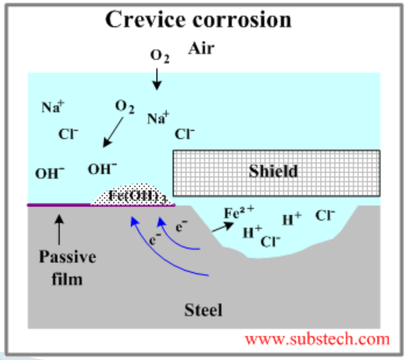


Forms of Corrosion

- **Pitting Corrosion**

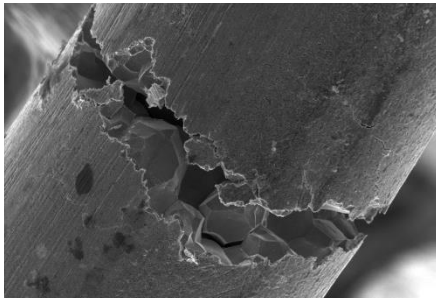


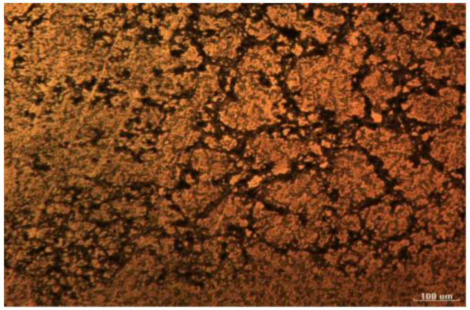
- **Crevice Corrosion**



Forms of Corrosion

- **Intergranular Corrosion**



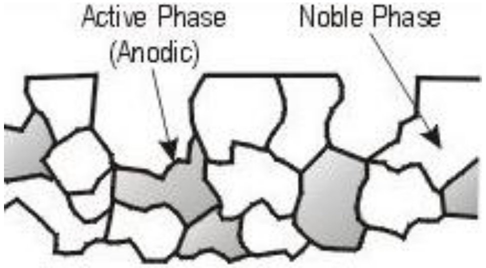


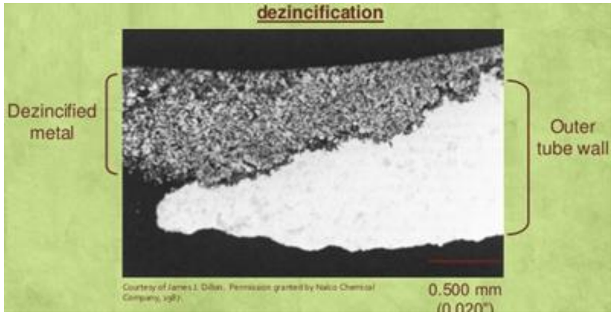
- **Stress Corrosion Cracking**

Forms of Corrosion

- **Erosion Corrosion**

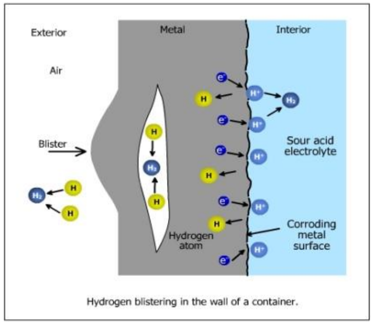
- **Selective leaching Corrosion**





Forms of Corrosion

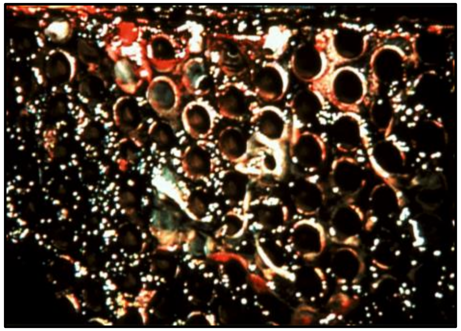
- **Hydrogen Damage**



- **Microbial Corrosion**

Micro biological growth

Bacteria, algae, Fungi



- Produce acidic waste that lowers pH and cause corrosion
- Form slime masses that foul & cause reduced heat transfer

- (Common biofilms are 4 times more insulating than $CaCO_3$ scale)

How do Microorganisms enter a Cooling Water System?

Classifications of Bacteria

Planktonic

- Free floating bacteria in bulk water

Sessile

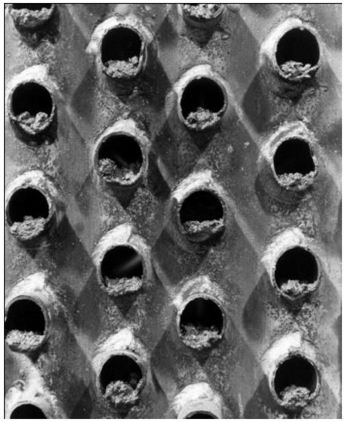
- Bacteria attached to surfaces
- Over 95% of bacteria in a cooling system are sessile and live in BIOFILMS

Factors affecting Boigouling formation

- NUTRIENT (Ammonia, oil, organic)
- WATER TEMPERATURE
- pH VALUE 6.0 : 9.0
- DISSOLVED OXYGEN
- SUN LIGHT
- NUMBER OF BACTERIA
- TURBIDITY
- SLIME VOLUME
- SLIME ADHESION DEGREE
- WATER FLOW RATE

Fouling

- Acumulation of solid material, other than scale.
  - Silt, Sand, Mud
  - Dirt & Dust
  - Process contaminants, e.g. Oils
  - Corrosion Products
  - Microbial growth



Calcuations

Site		volume	1,000 m3	Recirculation	1,000 m3/h	
	50 °C HOT SKIN			Temperature Drop	10.0 °C	
Date	9-May-18	40 °C HOT HX EXIT		Evaporation	15.4 m3/h	
	0.9 M-ALK FACTOR			Evaporation Factor	1.54 % per 10 °C	

	pH	M-ALK mg/l CaCO3	Ca mg/l CaCO3	Mg mg/l CaCO3	SiO2 mg/l	COND µS/cm	Cl mg/l	SO4 mg/l	% MU	LSI SKIN	LSI BULK	MgSi mg/l	CaMgSi mg/l	PURGE m3/h	t ½ days
1	7.60	125.0	150.0	100.0	10	420	60	100	100.0%						
2	0.00	0.0	0.0	0.0	0	0	0	0	0.0%						
CYCLES	7.60	125.0	150.0	100.0	10	420	60	100	100.0%	MAKE UP					
1.5	8.21	168.8	225.0	150.0	15	630	90	150		1.29	1.12	OK	OK	30.8	0.94
2.0	8.39	225.0	300.0	200.0	20	840	120	200		1.69	1.52	OK	OK	15.4	1.88
2.5	8.53	281.3	375.0	250.0	25	1050	150	250		2.01	1.84	OK	OK	10.3	2.81
3.0	8.64	337.5	450.0	300.0	30	1260	180	300		2.27	2.10	OK	OK	7.7	3.75
3.5	8.73	393.8	525.0	350.0	35	1470	210	350		2.48	2.32	OK	OK	6.2	4.69
4.0	8.81	450.0	600.0	400.0	40	1680	240	400		2.67	2.50	OK	HIGH	5.1	5.63
4.5	8.88	506.3	675.0	450.0	45	1890	270	450		2.84	2.67	OK	HIGH	4.4	6.56
5.0	8.95	562.5	750.0	500.0	50	2100	300	500		2.99	>2.8	HIGH	HIGH	3.9	7.50
5.5	9.01	618.8	825.0	550.0	55	2310	330	550		>3.0	>2.8	HIGH	HIGH	3.4	8.44

Chemical Treatment Programs

- ✓ Scale Inhibitors
- ✓ Corrosion Inhibitors
- ✓ Biocides

Scale Inhibitors

Operate through two different mechanisms.

1-nucleation inhibition:
Decreasing stability of the growing nucleons

2-crystal growth blocking

- Blocking of the growth processes of the growing crystals

Scale Inhibitors

Scaling	LSI	RSI/PSI	HEDP	PBTC	PAA
			(100% Active Basis)		
None	0.0	> 5.8	0.0	0.0	0.0
Slight	0.2	5.6 - 5.7	0.2	0.1	0.5
Moderate	0.5	5.3 – 5.5	0.5	0.3	1.0
Strong	1.0	4.7 – 5.2	1.0	0.5	2.2
Very Strong	1.5	4.3 - 4.6	2.0	1.2	4.0
Severe	2.0	4.1 – 4.2	3.0	1.8	x
Very Severe	2.5	3.9 – 4.0	x	2.4	x
Highly Stressed	> 2.7	< 3.9	x	x	x

HEDP= Hydroxyethylidene Diphosphonic Acid
PAA= Poly Acrylic Acid
PBTC = Phosphonobutane-1,2,4-Tricarboxylic Acid

Corrosion inhibitors

Anodic inhibitors

React with Me^{n+} on the anode, forming insoluble hydroxides which are deposited on the metal surface as insoluble film and impermeable to metallic ion.

Nitrates, molybdates, sodium chromates, phosphates, hydroxides and silicates

Cathodic inhibitors

Prevent the occurrence of the cathodic reaction of the metal. Have metal ions able to produce a cathodic reaction.

$Mg(OH)_2$, $Zn(OH)_2$, $Ni(OH)_2$

Thus producing insoluble compounds that precipitate on cathode.

Biocides

Oxidizing Biocides

- Cl_2
- NaOCl
- BrOCl
- Chlorine dioxide
- Hydrogen peroxide
- Ozone

Non-oxidizing Biocides

- BHAP: 2-Bromo-4-hydroxyacetophenone
- Glutaraldehyde: Pentane-1,5-dial
- Isothiazolines: Alkyl isothiazolin-3-ones
- Quats: Alkyldimethylbenzylammonium chloride

Biodispersants

Chemical Treatment Programs

- Moly/Phosphonate
- Alkaline /Zinc
- Stabilized Phosphate
- All Organic
- Oxidizing Biocides
- Non Oxidizing Biocides

Chemical Treatment Programs

<u>Moly/Phosphonate</u>

- For corrosive, low hardness &/or alkalinity water.
- Molybdate-based corrosion inhibitor phosphonate for scale inhibition
- Good at high skin temperatures.

- Molybdate : 6-16 ppm (as MoO_4)
- Phosphonate : 1-2 ppm (as PO_4)
- Calcium : 0-500 ppm
- M-Alkalinity : 50 -2,000 ppm
- Temperature : 57- 82°C
- Conductivity : 2,000 uS/cm

Chemical Treatment Programs

<u>Alkaline /Zinc</u>

- low level of zinc with ortho phosphate for corrosion control
- Polymeric dispersant used for scale control at high pH
- Zinc provides cathodic corrosion protection
- Ortho phosphate provides anodic corrosion protection
- Operate at higher pH to provide excellent corrosion

- Zinc : 0.5-2.0 ppm
- Ortho PO_4 : Extremely variable
- Calcium : 15-1,000 ppm
- M-Alkalinity : 50 -1,500 ppm
- Temperature : 71°C max.
- Conductivity : 6,000 micromhos max.

Chemical Treatment Programs

- **Stabilized Phosphate**
- High levels of ortho PO_4 to provide corrosion protection.
- Polymeric dispersant provides calcium phosphate stabilization.
- Operates at near-neutral pH.
- Low make-up calcium &/or M-alkalinity

O-PO_4	: 8 -17 ppm (Ca dependent)
Calcium	: 15 -1,000 ppm
pH	: 6.8-8.4 (Ca dependent)
Temperature	: 66°C max.
Conductivity	: 7,500 micromhos max.

Chemical Treatment Programs

- **<u>All Organic</u>**
- Non-heavy metal/phosphate program
- High pH & alkalinity conditions to provide corrosion protection in a scale forming cooling system environment.
- Organic scale inhibitors prevent mineral deposits.

- Calcium : 80-900 ppm
- M-Alkalinity : 300-500 ppm
- pH :8.5-9.4
- Temperature :43-60°C
- Conductivity :4,500 microS

Microbial control using Chemical Treatment

- Oxidizing Biocides

- Penetrate microorganism's cell wall
- Burn-up the internals of the organism
- Effective against all types of bacteria.
- Kill everything given sufficient concentration levels & contact time

- Examples
  - Cl_2
  - NaOCl
  - BrOCl
  - Ozone
  - Chlorine dioxide
  - Hydrogen peroxide

Microbial control using Chemical Treatment

- Non-oxidizing Biocides

BHAP

- 2-Bromo-4-hydroxyacetophenone for bacteria and, slimes.
- Useful for once-through cooling systems
- Dose rate is 1 to 3 ppm
- For recirculating cooling systems10 to 20 ppm up to 80ppm

Microbial control using Chemical Treatment

- Non-oxidizing Biocides

Glutaraldehyde

- Pentane-1,5-dial.
- good penetrating ability.
- Effective against SRBs and biofilms. NOT against algae and fungi.
- Cross-link outer proteins of cell
- Fast-acting biocide (3 to 4 hours, up to 4 or 6 hours with difficult slimes) a wide pH range (typically pH 6.5 to 9.0)
- Typical use concentration is 100 to125 ppm up to 200 to 300 ppm

Microbial control using Chemical Treatment

- Non-oxidizing Biocides

Isothiazolines

- Alkyl⌕ isothiazolin-3-ones
- Bactericide and algaecide
- wide range of pH
- Inhibiting microbial respiration and food transport through the cell wall.
- Contact time is typically 5 to 6 hours.
- Dose⌕ rate is typically 50 to 120 ppm

Microbial control using Chemical Treatment

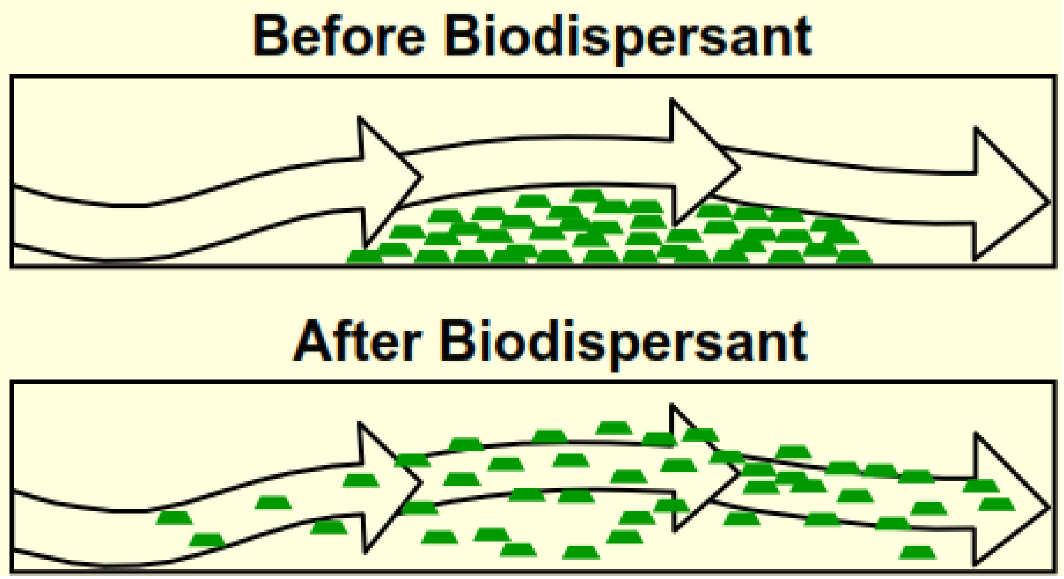
- Non-oxidizing Biocides

Quats (ADBACs)

- Alkyl dimethyl benzyl ammonium chlorides “Quaternary ammonium compounds”.
- The kill mechanism is due to the cationic nature, whereby an electrostatic bond is formed with the cell wall, which affects permeability and protein denaturing.
- Optimum pH 6.5-8.5
- Deactivated by high hardness (typically over 500 ppm.
- dose rate 50 to 100 ppm
- Contact time is typically 4 to 6 hours.

Microbial control using Chemical Treatment

- Biodispersants



Monitoring of cooling systems

- Follow up system hydraulics
- Water chemistry
- Measuring corrosion rate
- Measuring scaling rate
- Bacterial count
- Monitoring chemicals dozing rate
- Devises and equipment